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(54) PRESSURE EQUALIZATION IN EARPHONES

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H04R 1/28 (2006.01)

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CPC ***H04R 1/1066*** (2013.01); ***H04R 1/105*** (2013.01); ***H04R 1/1016*** (2013.01); ***H04R 1/1058*** (2013.01); ***H04R 1/1075*** (2013.01); ***H04R 1/2826*** (2013.01); ***H04R 1/2884*** (2013.01); *H04R 2201/10* (2013.01); *H04R 2420/07* (2013.01); *H04R 2460/11* (2013.01)

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CPC H04R 1/1016; H04R 1/105; H04R 1/1066; H04R 1/28–1/2819; H04R 1/2838–1/2849; H04R 1/2869–1/2896; H04R 25/02; H04R 25/45; H04R 25/456; H04R 25/48; H04R 25/60; H04R 25/608; H04R 2201/029; H04R 2201/10; H04R 2460/09; H04R 2460/11
See application file for complete search history.

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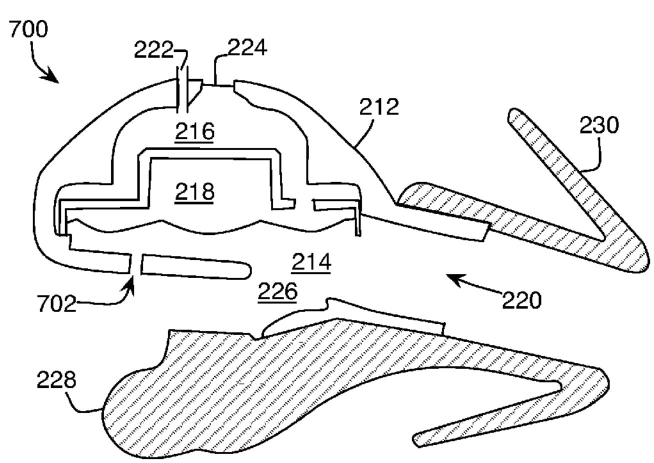
Assistant Examiner — Joshua Kaufman

(57) **ABSTRACT**

A headphone includes an electro-acoustic transducer dividing an enclosed volume into a front volume and a rear volume, a first port in the housing coupling the front volume to an ear canal of a user, a second port in the housing coupling the front volume to space outside the ear, a third port in the housing coupling the rear volume to space outside the ear, and an ear tip configured to surround the first port and including a flap to seal the ear canal from space outside the ear. The second port has a diameter and a length that provide an acoustic mass with an acoustic impedance with a high reactive component and a low resistive component, reducing the occlusion effect that otherwise results from sealing the ear.

25 Claims, 7 Drawing Sheets



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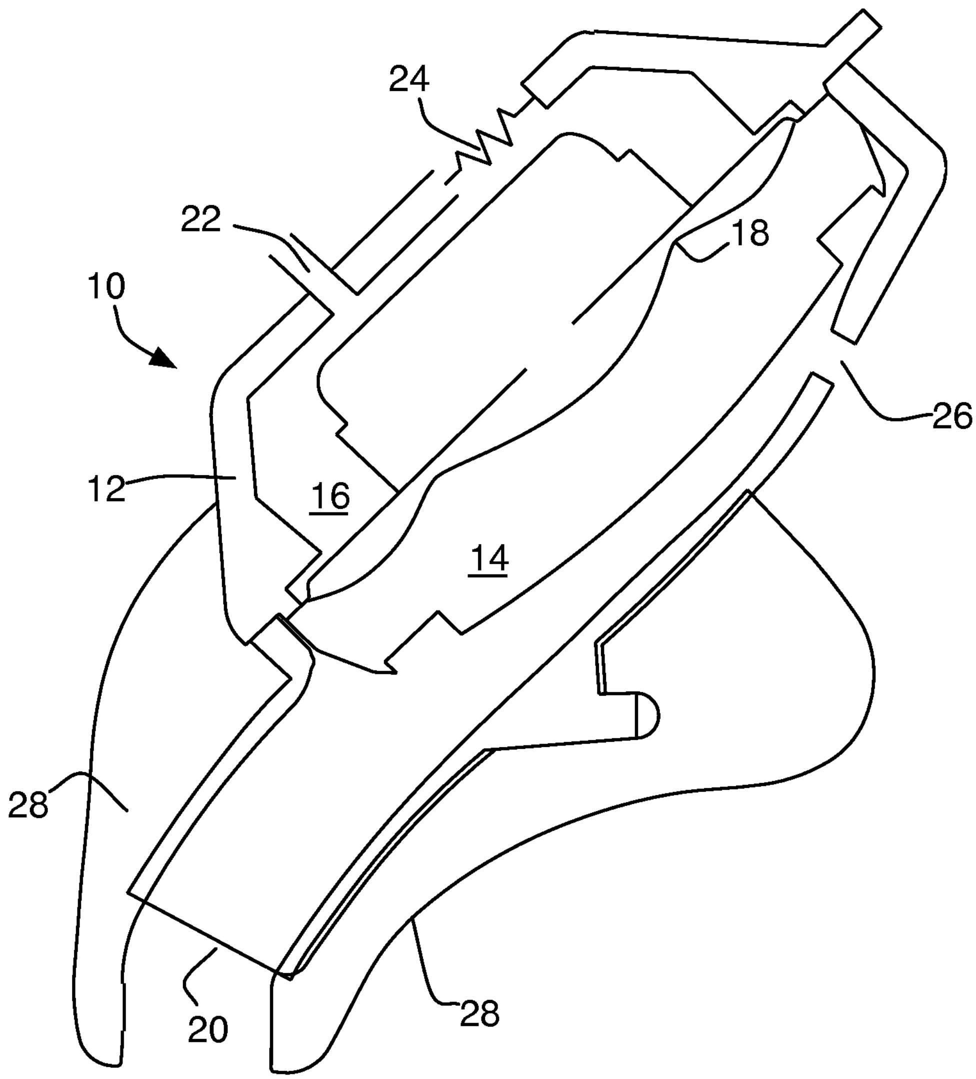


Fig. 1
(prior art)

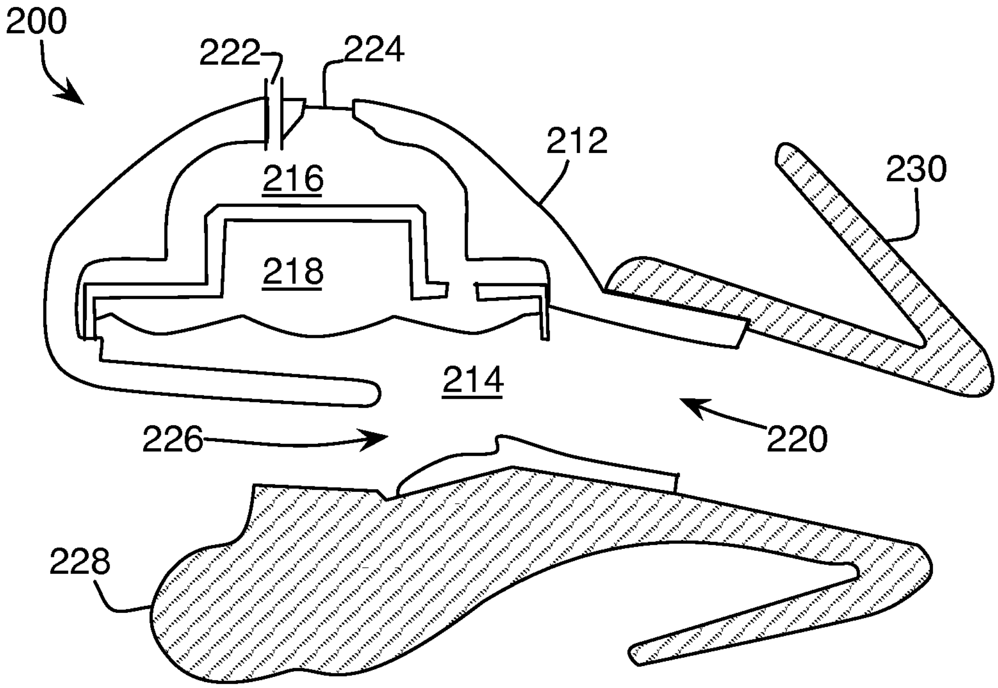

200
222
224
212
230
216
218
214
226
220
228

Fig. 2

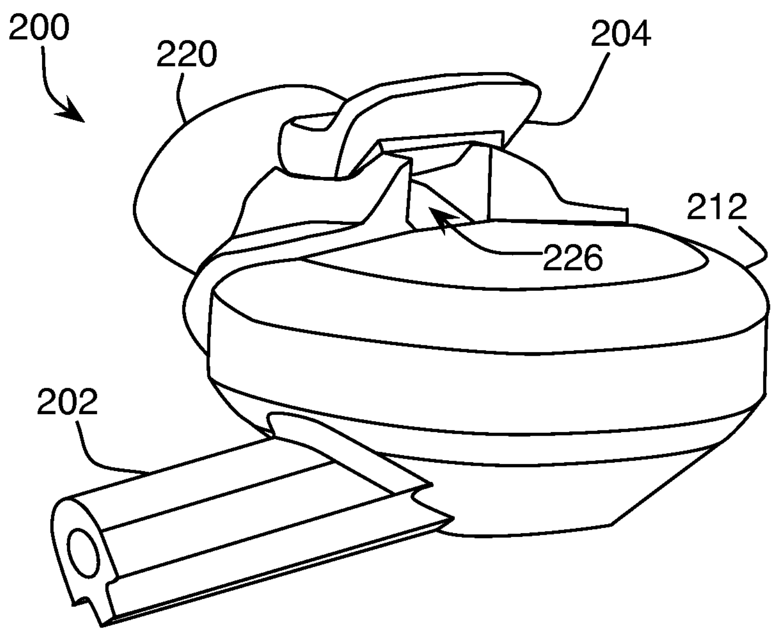

200
220
204
212
226
202

Fig. 3

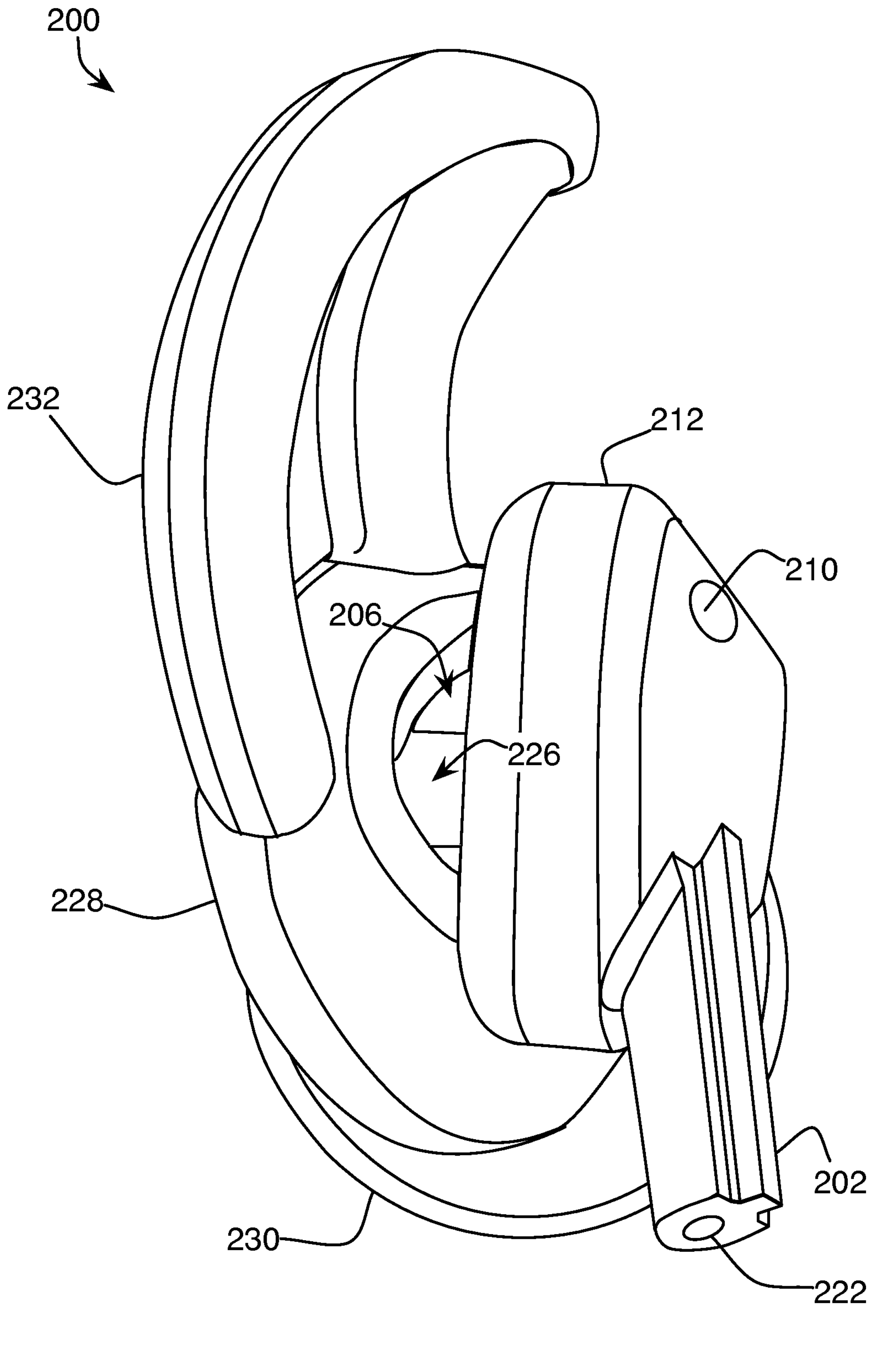


Fig. 4

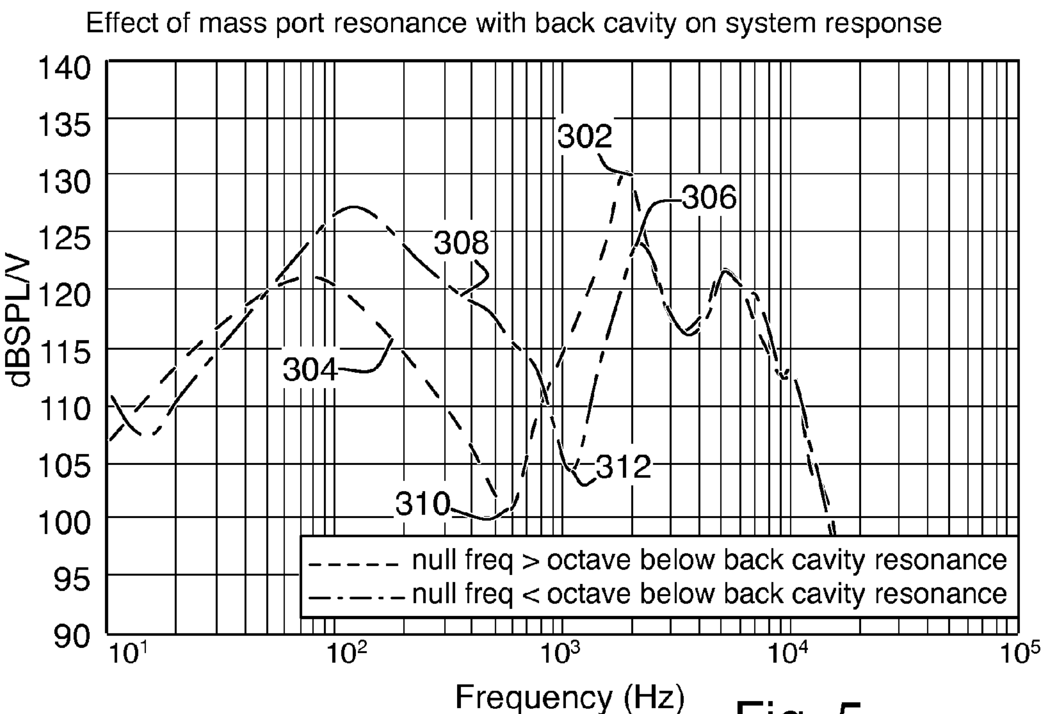

Effect of mass port resonance with back cavity on system response
dBSPL/V
140
135
130
125
120
115
110
105
100
95
90
10^1
10^2
10^3
10^4
10^5
Frequency (Hz)
302
306
308
304
310
312
null freq > octave below back cavity resonance
null freq < octave below back cavity resonance

Fig. 5

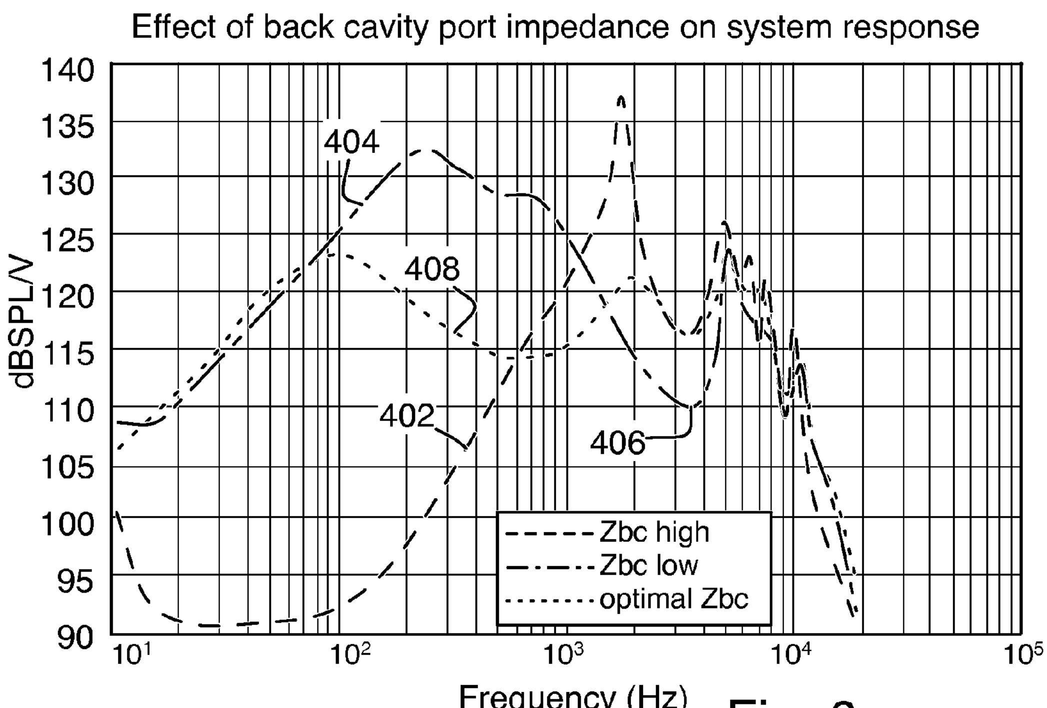
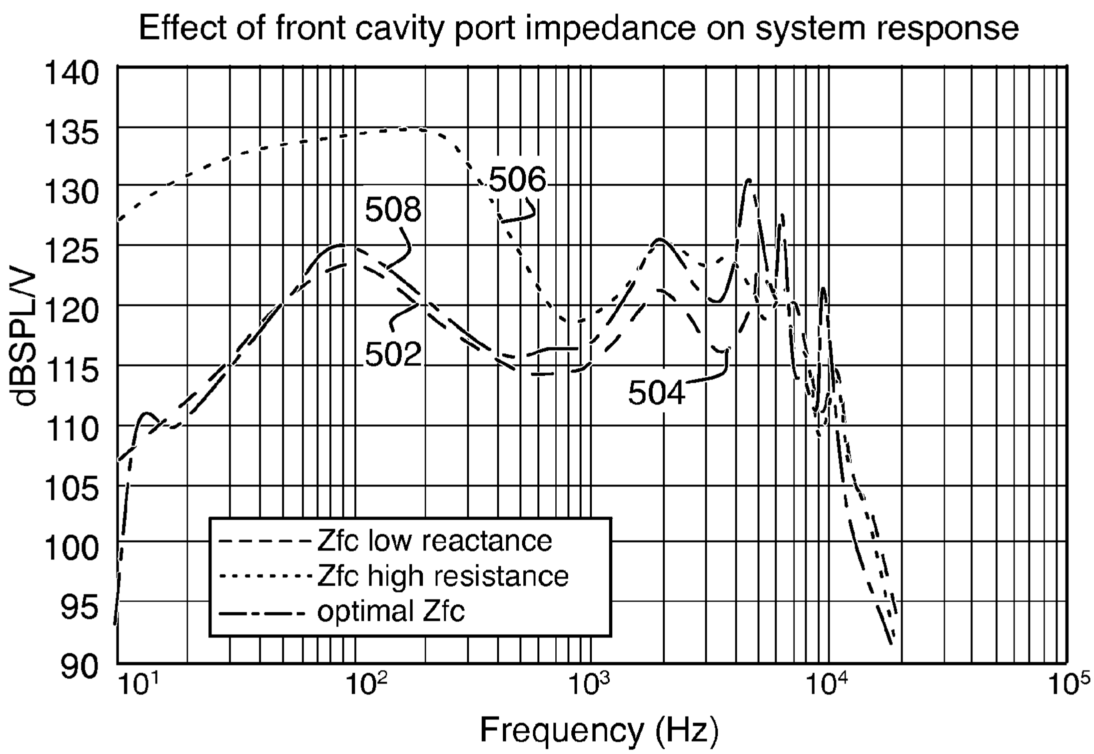

Effect of back cavity port impedance on system response
dBSPL/V
140
135
130
125
120
115
110
105
100
95
90
10^1
10^2
10^3
10^4
10^5
Frequency (Hz)
404
408
402
406
Zbc high
Zbc low
optimal Zbc

Fig. 6



Effect of front cavity port impedance on system response
140
135
130
125
120
115
110
105
100
95
90
dBSPL/V
10^1
10^2
10^3
10^4
10^5
Frequency (Hz)
506
508
502
504
Zfc low reactance
Zfc high resistance
optimal Zfc

Fig. 7

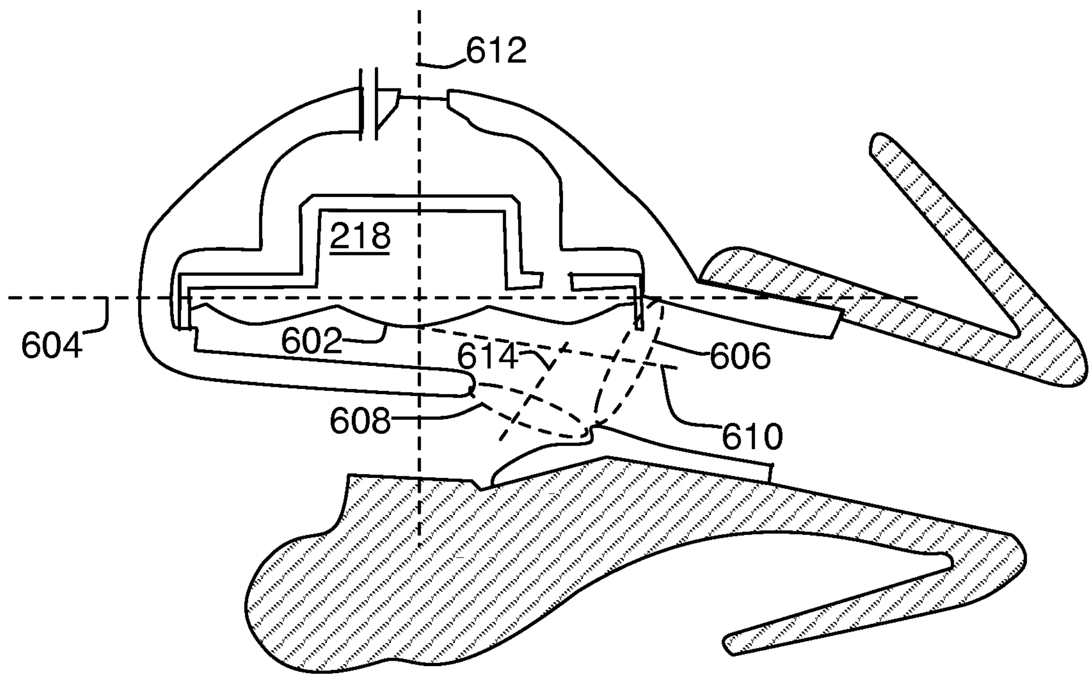


Fig. 8

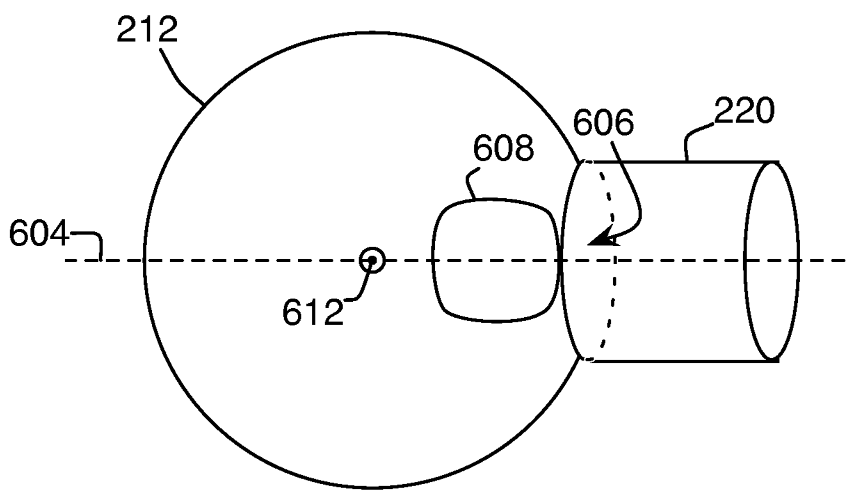


Fig. 9

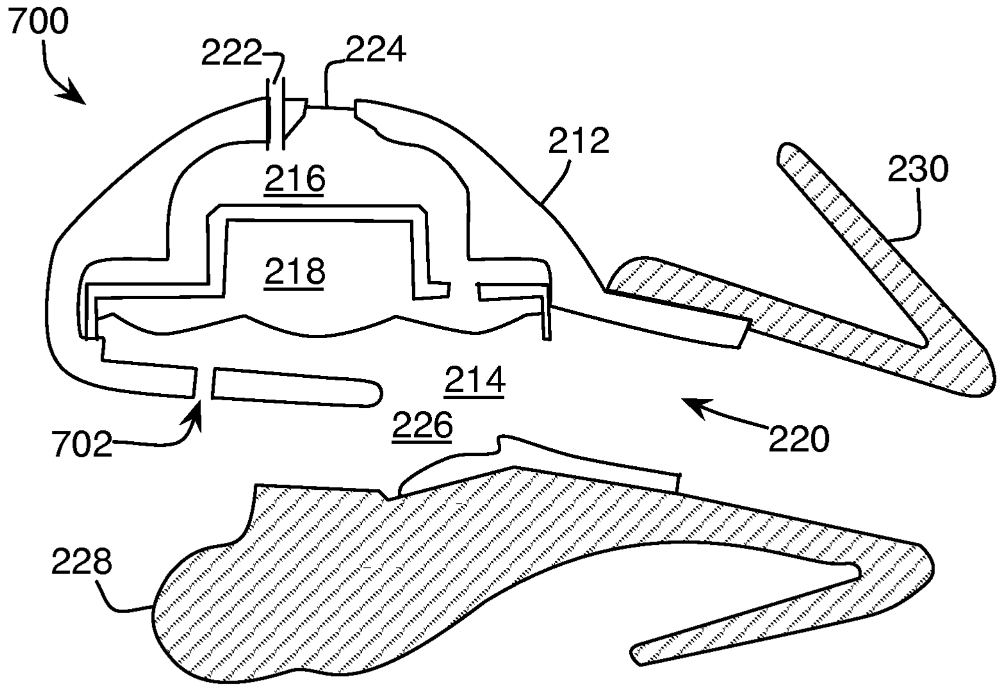

700
222
224
212
230
216
218
214
702
226
220
228

Fig. 10

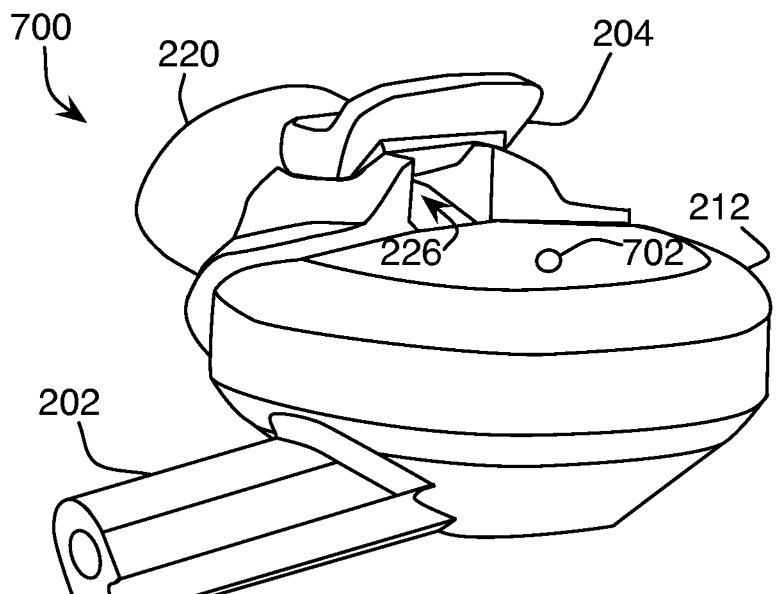

700
220
204
212
226
702
202

Fig. 11

PRESSURE EQUALIZATION IN EARPHONES

BACKGROUND

This disclosure relates to pressure equalization in earphones.

Audio headphones, and in particular, in-ear earphones meant to be seated at least partially in a user's ear canal or ear canal entrance, sometimes have a number of openings, or ports, coupling the volumes within the earphones to the ear canal, to each other, or to free space. As shown in FIG. **1**, a typical earphone **10** has a housing **12** defining a front cavity **14** and a rear cavity **16**, separated within the body by a electroacoustic transducer, or driver, **18**. A main output port **20** couples the front cavity to the ear canal so that the user can hear sound generated by the driver **18**. Rear ports **22** and **24** couple the rear cavity to free space to control the acoustic properties of the back cavity and their effect on the audio output or response through the output port **20**, as described in U.S. Pat. No. 7,916,888, the entire contents of which are incorporated here by reference. A front port **26** similarly controls the acoustic properties of the front cavity, as described in U.S. Pat. No. 8,594,351, the entire contents of which are incorporated here by reference. The front port **26** also serves as a pressure equalization (PEQ) port because it couples the front cavity to free space. A PEQ port serves to relieve pressure created in the front cavity when the earphone is inserted into the ear. An ear tip **28** serves as an ergonomic interface between the housing **12** and the ear.

SUMMARY

In general, in one aspect, a headphone includes a housing defining an enclosed volume, an electro-acoustic transducer dividing the enclosed volume into a front volume and a rear volume, a first port in the housing arranged to couple the front volume to an ear canal of a user when the headphone is worn, a second port in the housing arranged to couple the front volume to space outside the ear of the user when the headphone is worn, a third port in the housing arranged to couple the rear volume to space outside the ear of the user when the headphone is worn, and an ear tip configured to surround the first port and including a flap to seal the ear canal from space outside the ear when the headphone is worn. The second port has a diameter and a length that provide an acoustic mass with an acoustic impedance with a high reactive component and a low resistive component.

Implementations may include one or more of the following, in any combination. The second port may have a diameter and a length that provide the second port with a low acoustic impedance at low frequencies and a high acoustic impedance at high frequencies. The housing may include an extended tab for retaining the ear tip, and the second port may include an exit from the housing positioned next to the extended tab, with the extended tab between the first port and the second port exit. The ear tip may include a void positioned to surround the second port exit, the ear tip protecting the second port exit from blockage. The void may not impart additional acoustic impedance to the second port. The ear tip may be formed from materials having at least two different hardnesses, the portion of the ear tip defining the void being of a greater hardness than the portion of the ear tip forming the seal. The transducer may include a diaphragm that is generally characterized by a fist plane, is radially symmetric along a first axis perpendicular to the plane, and is bounded by an outer edge, the first port extending from an entrance into the front volume near the outer edge of the transducer, and the second port extending from an entrance into the front volume, the second port entrance being located along a line connecting the first axis to the first port entrance. The second port entrance may be located facing the diaphragm, between the first port and the first axis.

The first port may have a lower characteristic acoustic impedance than the second port. The second port may have a characteristic acoustic impedance of at least 6.8×10^6 at 20 Hz and at least 3.1×10^7 at 3 kHz. The third port may have a characteristic acoustic impedance of at least 8.0×10^6 at 20 Hz and at least 3.1×10^8 at 3 kHz the second port may have a characteristic acoustic impedance of at least 6.8×10^6 at 20 Hz and at least 3.1×10^7 at 3 kHz. A fourth port in the housing may be arranged to couple the front volume to space outside the ear of a user when the headphone is worn, the fourth port having a diameter and a length that provide the fourth port with a high acoustic impedance with a large resistive component and a low reactive component. The fourth port may have a characteristic acoustic impedance of at least 8.3×10^7 kg/m^4 at 3 kHz.

In general, in one aspect, a headphone includes a housing defining an enclosed volume, an electro-acoustic transducer dividing the enclosed volume into a front volume and a rear volume, a first port in the housing arranged to couple the front volume to an ear canal of a user when the headphone is worn, a second port in the housing arranged to couple the front volume to space outside the ear of the user with a characteristic acoustic impedance of at least 6.8×10^6 at 20 Hz and at least 3.1×10^7 at 3 kHz when the headphone is worn, a third port in the housing arranged to couple the rear volume to space outside the ear of the user with a characteristic acoustic impedance of at least 8.0×10^6 at 20 Hz and at least 3.1×10^8 at 3 kHz when the headphone is worn, and an ear tip configured to surround the first port and form a seal between the housing and the ear canal when the headphone is worn.

In general, in one aspect, a headphone includes an ear tip configured to seal the headphone to the ear canal to form an enclosed volume including the ear canal and a front cavity of the headphone, a front reactive port coupling the otherwise-sealed front cavity to space outside the headphone, to provide a consistent response across the audible spectrum, and a rear reactive port and a rear resistive port coupling a back cavity to space outside the headphone in parallel, to provide a high level of output for a given input signal level in combination with the seal.

Implementations may include one or more of the following, in any combination. The headphone may be coupled to the ear canal through a characteristic acoustic impedance of less than 6.8×10^6 at 20 Hz and less than 3.1×10^7 at 3 kHz. The front reactive port may have a characteristic acoustic impedance of at least 6.8×10^6 at 20 Hz and at least 3.1×10^7 at 3 kHz the rear reactive port may have a characteristic acoustic impedance of at least 8.0×10^6 at 20 Hz and at least 3.1×10^8 at 3 kHz.

Advantages include providing a consistent response across the audible spectrum and reduction of the occlusion effect caused by sealing the ear canal.

All examples and features mentioned above can be combined in any technically possible way. Other features and advantages will be apparent from the description and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**, **2**, **8**, and **10** show cross-sectional views of earphones.

FIGS. **3**, **4**, and **11** show isometric views of the earphone of FIG. **2**.

FIGS. **5**, **6**, and **7** show graphs of earphone response.

FIG. **9** shows a schematic plan view of the earphone of FIG. **2**.

DESCRIPTION

Headphones in general, and in-ear headphones in particular, can be broadly divided into two categories with regard to how well they seal to the ear. Isolating headphones are intended to create a sealed front cavity coupling the driver to the ear canal, preventing air flow (and sound pressure leakage) between the ear canal and the environment. Open headphones are intended to not create such a seal, so that air and therefore sound can flow between the environment and the ear canal. In many cases, the choice between isolating and open is made to balance such factors as fidelity, sensitivity, isolation, and comfort. Of course, controlling any of these factors also requires proper configuration of the headphone acoustics. Open headphones tend to be more susceptible to interference from outside noises, while isolating headphones tend to be less comfortable.

One of the reasons isolating headphones tend to be less comfortable than other types, beyond the simple fact that they put more pressure on the flesh of the ear, is that they cause what is called the occlusion effect, the distortion of the user's perception of his own voice when his ears are plugged. When a user's ear is blocked, whether by earphones, earplugs, or fingers, high-frequency components of the user's voice travelling through the air from mouth to ear are attenuated. At the same time, low-frequency components of the voice travel through the head and directly into the ear canal through the side walls of the ear canal, and are amplified by the acoustic effects of the sealed ear canal relative to how loud they are when the ear is open. These sounds are not just present while the high-frequency sounds are absent, but are actually amplified as a result of being trapped inside the ear canal. The total effect makes the user's voice sound deeper and unnatural, but only to himself. Even when not speaking, sounds such as blood flow and jaw movement are also amplified by the sealed ear canal, causing a stuffed-up sensation independent of the physical presence of whatever is plugging the ear. Earphones that seal the ear canal can also impact the user's situational awareness, that is, his perception of environmental sounds. Sometimes this is desired, but other times it is not. PEQ ports like that shown in FIG. **1** can reduce the occlusion effect, by relieving some of the pressure in the ear canal, but they generally also reduce low frequency output and isolation, taking away some of the advantage intended to be gained by using an isolating earphone in the first place.

As described below, PEQ ports and rear cavity ports in an earphone that seals to the ear canal are configured in such a way that the occlusion effect is minimized and situational awareness is improved, without losing the improved sensitivity and subsequent control over response characteristics that is provided by sealing the earphone to the ear canal. The sealing ear tip also provides a consistent low-frequency acoustic response across various fits. As shown in FIGS. **2** and **4**, such a headphone **200** has a sealing flange **230** extending from the ear tip **228**. FIG. **3** shows the headphone **200** with the ear tip removed. The flange contacts the edge of the transition between the user's ear canal and concha, to seal the ear canal without protruding deeply into it, as described in U.S. Patent publication 2013/230204, the contents of which are incorporated here by reference. In combination with this, a PEQ port **226** coupling the front cavity **214** to space outside the ear is configured to be reactive, that is, the port is dimensioned such that the air in it behaves as an acoustic mass, providing the port with a low acoustic impedance at low frequencies, and a higher acoustic impedance at high frequencies. Rear ports **222** and **224** couple the rear cavity **216** to space outside the ear, and provide a reactive and resistive impedance, respectively, further tuning the response of the headphone. As in FIG. **1**, the housing **212** defines the front and rear cavities, separated by the driver **218**. The nozzle **220** connects the front cavity to the ear canal.

FIGS. **3** and **4** show external views of the same earphone, with the ear tip **228** removed for clarity in FIG. **3**. The housing **212** includes an extension **202** containing the reactive port **222**. A tab **204** (FIG. **3**) retains the ear tip **228** (FIG. **4**) when it is installed. In this example, the PEQ port **226** exits the housing under the retaining tab **204**. This has the advantage of protecting the PEQ port from being blocked when the earphone is seated in the ear.

As shown in FIG. **4**, a gap **206** in the shaped of the ear tip surrounds the PEQ port and further protects the port from being blocked. FIG. **4** also shows an optional positioning and retaining member **232** that extends from the ear tip **228** and seats in the pinna of the ear, to help position and retain the earphone, as described in U.S. Pat. No. 8,249,287, the contents of which are incorporated here by reference. Other options for the construction and packaging of the back cavity ports are described in U.S. patent application Ser. No. 13/606,149 (now U.S. Pat. No. 8,670,586), the contents of which are incorporated here by reference. A wire exit **210** allows wire leads from the driver inside the housing **212** to reach either a cable, in a wired headset, or integrated electronics, in a wireless or otherwise active headset.

FIG. **5** shows two potential response curves for an earphone like that shown in FIG. **2**, and in particular, it shows the effect of a reactive back-cavity port **222** that resonates with the back cavity volume **216**. The front and back cavities each enclose a volume of air, and therefore each have an acoustic compliance. The driver **218** has a moving mass and an acoustic compliance, which is also measured in units of volume, i.e., cm^3, representing the volume of air having an equivalent acoustic compliance. The compliance of the back cavity and the mass of the driver create a resonance in the frequency response, which can be seen in peaks **302** on curve **304** and **306** on curve **308** in FIG. **5**. For a typical earphone with a 0.15 cm^3 back cavity and a driver with a compliance of 20 to 50 cm^3 and a moving mass of 2.5 to 20 mg, the resonance is between 1 and 3 kHz. The reactive port **222** in the back cavity also has an acoustic mass (hence it is sometimes called a mass port), and this mass resonates with the back cavity compliance to create a null in the response, seen in troughs **310** on curve **304** and **312** in curve **308**. In some examples, it is desirable that the mass port null be at least an octave below the driver peak. Doing this allows the resistance of the resistive port **224** to damp the response, i.e., lower the peaks, without lowering the response below where it retains enough sensitivity to be effectively equalized.

In addition to resonances between the different components causing peaks and nulls, the acoustic impedance of the ports also affects the response. FIG. **6** shows the range of effect that the combined impedance of the back cavity ports has on the total response of the earphone. As curve **402** shows, if the back cavity port impedance Zbc is too high, there is little to no output in lower frequencies. On the other hand, curve **404** shows that if the Zbc is too low, while low frequency response is maintained, mid-frequency response can dip too low, as shown by the trough **406** around 4 to 5 kHz. Such a low dip can prevent the earphone from having enough sensitivity at that range to be equalized to a desirable response. Curve **408** shows a more optimized response, where the impedance of the back cavity ports is balanced to give up some of the higher response between 200 Hz and 1 kHz, from the low-impedance curve **404**, and recover the response between 1.5 kHz and 5 kHz, so that the total curve remains above about 115 dBSPL from 30 Hz and up.

Providing a front cavity PEQ having a low acoustic resistance can improve the occlusion effect and situational awareness, as it effectively un-seals the front cavity from the ear canal, but at the expense of output. The midband output can be preserved by maintaining a high reactance in the PEQ port, preserving its impedance while allowing the low resistance needed to avoid occlusion. FIG. **2** shows the response for several variations in front cavity PEQ impedance Zfc. Curve **502** shows the response with a low reactance in Zfc. The overall response is high enough in the middle-low frequencies, but dips too low to be electronically compensated at both the low and high end, in particular at trough **504** at 3 to 4 kHz. Curve **506** shows the response with a high resistance in Zfc—this raises the response in the low end too high, making the occlusion effect unpleasant. Curve **508** shows the response with an optimized Zfc, where a balance of higher reactance and lower resistance provides a response that is high enough across a significant frequency range that sensitivity can be traded for fidelity through equalization. As mentioned in regard to FIG. **2**, this optimization, a PEQ port with high reactance and low resistance, can be achieved by providing a port that has a larger cross sectional area, lowering its acoustic resistance, combined with enough length to contain a reactive acoustic mass of air. In some examples, the port is sized to provide a characteristic acoustic impedance that has a resistive value of at least 6.83×10^6 kg/m^4 at 20 Hz, and a reactive value of 30.10×10^7 at 3 kHz, when used with a back cavity mass port having a characteristic acoustic impedance of 8.00×10^6 at 20 Hz and 3.10×10^8 at 3 kHz. The impedances of the PEQ port at both frequencies could be increased by up to 3 dB without affecting occlusion significantly. Note that the resistive component of the PEQ port is not eliminated completely—the remaining acoustic resistance at low frequency preserves low-frequency output as it shifts the roll-off from second order (if there we no resistance) to first-order. Although this does preserve some occlusion effect, the human voice is not significant in this band, while music does tend to have significant energy.

In addition to its impedance, the location of the PEQ port is also controlled to improve headphone performance. Positioning the PEQ port behind the retaining tab, as described above, happens to position the port entrance (the end of the port inside the front cavity) next to the entrance to the nozzle **220**, which creates a symmetric loading on the driver **218**. This avoids introducing undesirable features or resonances in the acoustic response caused by asymmetric loading. In some examples, as shown in FIGS. **8** and **9**, the transducer diaphragm **602**, is generally planar, characterized by a plane **604**. The nozzle has an entrance **606** at the edge of the diaphragm, though it is not necessarily in the plane **604** of the diaphragm. The PEQ port has an entrance **608** to the front cavity that is positioned to align with a radial line **610** from the centerline of the transducer (line **612**) to the entrance of the nozzle. That is, the line **612** corresponds to an axis around which the diaphragm is radially symmetric, the line **610** intersects the line **612** and passes through the entrance **606** of the nozzle, and a line **614** intersects the line **610** and passes through the entrance **608** of the PEQ port.

In some examples, it is advantageous to add a second PEQ port to further shape the passive frequency response of the headphone. As shown in the modified earbud **700** in FIGS. **10** and **11**, an additional port **702** is added to the front cavity. This port **702** is shown as a small hole, but it could also be covered by a screen like port **224**. While the reactive port **226** has an overall low impedance, an additional feature of the small PEQ port used previously, damping high-frequency peaks, is lost. Adding a low-reactance, high-impedance PEQ port in parallel to the high-reactance, low-impedance PEQ port **226** damps such peaks without impacting the low frequency response that was optimized by the large port. A characteristic impedance of 2.0×10^7 kg/m^4 or more at 3 kHz will provide such an advantage. For example, a 4 mm diameter hole covered by a mesh having an impedance of 260 Rayl will provide such an impedance.

A number of implementations have been described. Nevertheless, it will be understood that additional modifications may be made without departing from the scope of the inventive concepts described herein, and, accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A headphone comprising:

a housing defining an enclosed volume;

an electro-acoustic transducer dividing the enclosed volume into a front volume and a rear volume;

a first port in the housing arranged to couple the front volume to an ear canal of a user when the headphone is worn;

a second port in the housing arranged to couple the front volume to space outside the ear of the user when the headphone is worn;

a third port in the housing arranged to couple the rear volume to space outside the ear of the user when the headphone is worn; and

an ear tip configured to surround the first port and including a flap to seal the ear canal from space outside the ear when the headphone is worn, the housing comprising an extended tab for retaining the ear tip;

wherein

the second port has a diameter and a length that provide an acoustic mass with an acoustic impedance with a high reactive component and a low resistive component, and

an entrance to the first port is positioned next to a first side of the extended tab and an entrance to the second port is positioned next to a second side of the extended tab, such that the electro-acoustic transducer is approximately symmetrically loaded.

2. The headphone of claim **1**, wherein the second port has a diameter and a length that provide the second port with a low acoustic impedance at low frequencies and a high acoustic impedance at high frequencies.

3. The headphone of claim **1**, wherein the ear tip includes a void positioned to surround the second port exit, the ear tip protecting the second port exit from blockage.

4. The headphone of claim **3**, wherein the void does not impart additional acoustic impedance to the second port.

5. The headphone of claim **3**, wherein the ear tip is formed from materials having at least two different hardnesses, the portion of the ear tip defining the void being of a greater hardness than the portion of the ear tip forming the seal.

6. The headphone of claim **1**, wherein:

the transducer includes a diaphragm that is generally characterized by a first plane, is radially symmetric along a first axis perpendicular to the plane, and is bounded by an outer edge;

the first port extends from an entrance into the front volume near the outer edge of the transducer; and the second port extends from an entrance into the front volume, the second port entrance being located along a line connecting the first axis to the first port entrance.

7. The headphone of claim **6**, wherein the second port entrance is located facing the diaphragm, between the first port and the first axis.

8. The headphone of claim **1**, wherein the first port has a lower characteristic acoustic impedance than the second port.

9. The headphone of claim **8**, wherein the second port has a characteristic acoustic impedance of at least 6.8×10^6 kg/m^4 at 20 Hz and at least 3.1×10^7 kg/m^4 at 3 kHz.

10. The headphone of claim **9**, wherein the third port has a characteristic acoustic impedance of at least 8.0×10^6 kg/m^4 at 20 Hz and at least 3.1×10^8 kg/m^4 at 3 kHz.

11. The headphone of claim **1**, wherein the second port has a characteristic acoustic impedance of at least 6.8×10^6 kg/m^4 at 20 Hz and at least 3.1×10^7 kg/m^4 at 3 kHz.

12. The headphone of claim **1**, further comprising a fourth port in the housing arranged to couple the front volume to space outside the ear of a user when the headphone is worn, the fourth port has a diameter and a length that provide the fourth port with a high acoustic impedance with a large resistive component and a low reactive component.

13. The headphone of claim **12**, wherein the fourth port has a characteristic acoustic impedance of at least 2.0×10^7 kg/m^4 at 3 kHz.

14. A headphone comprising:

a housing defining an enclosed volume;

an electro-acoustic transducer dividing the enclosed volume into a front volume and a rear volume;

a first port in the housing arranged to couple the front volume to an ear canal of a user when the headphone is worn;

a second port in the housing arranged to couple the front volume to space outside the ear of the user with a characteristic acoustic impedance of at least 6.8×10^6 kg/m^4 at 20 Hz and at least 3.1×10^7 kg/m^4 at 3 kHz when the headphone is worn;

a third port in the housing arranged to couple the rear volume to space outside the ear of the user with a characteristic acoustic impedance of at least 8.0×10^6 kg/m^4 at 20 Hz and at least 3.1×10^8 kg/m^4 at 3 kHz when the headphone is worn; and

an ear tip configured to surround the first port and form a seal between the housing and the ear canal when the headphone is worn, wherein:

the housing comprises an extended tab for retaining the ear tip, and

an entrance to the first port is positioned next to a first side of the extended tab and an entrance to the second port is positioned next to a second side of the extended tab, such that the electro-acoustic transducer is approximately symmetrically loaded.

15. The headphone of claim **14**, wherein the ear tip includes a void positioned to surround the second port exit, the ear tip protecting the second port exit from blockage.

16. The headphone of claim **15**, wherein the void does not impart additional acoustic impedance to the second port.

17. The headphone of claim **15**, wherein the ear tip is formed from materials having at least two different hardnesses, the portion of the ear tip defining the void being of a greater hardness than the portion of the ear tip forming the seal.

18. The headphone of claim **14**, wherein:

the transducer includes a diaphragm that is generally characterized by a first plane, is radially symmetric along a first axis perpendicular to the plane, and is bounded by an outer edge;

the first port extends from an entrance into the front volume near the outer edge of the transducer; and

the second port extends from an entrance into the front volume, the second port entrance being located along a line connecting the first axis to the first port entrance.

19. The headphone of claim **18**, wherein the second port entrance is located facing the diaphragm, between the first port and the first axis.

20. A headphone comprising:

an ear tip configured to seal the headphone to an ear canal of a user to form an enclosed volume including the ear canal and a front cavity of the headphone,

a housing comprising an extended tab for retaining the ear tip,

a front reactive port coupling the otherwise-sealed front cavity to space outside the headphone, to provide a consistent response across the audible spectrum, wherein the extended tab and ear tip cooperate to form a channel that surrounds the front reactive port, the channel protecting the front reactive port from blockage when the headphone is worn in the user's ear, and

a rear reactive port and a rear resistive port coupling a back cavity to space outside the headphone in parallel, to provide a high level of output for a given input signal level in combination with the seal.

21. The headphone of claim **20**, wherein the headphone is coupled to the ear canal through a characteristic acoustic impedance of less than 6.8×10^6 kg/m^4 at 20 Hz and less than 3.1×10^7 kg/m^4 at 3 kHz.

22. The headphone of claim **20**, wherein the front reactive port has a characteristic acoustic impedance of at least 6.8×10^6 kg/m^4 at 20 Hz and at least 3.1×10^7 kg/m^4 at 3 kHz.

23. The headphone of claim **20**, wherein the rear reactive port has a characteristic acoustic impedance of at least 8.0×10^6 kg/m^4 at 20 Hz and at least 3.1×10^8 kg/m^4 at 3 kHz.

24. The headphone of claim **20**, further comprising a front resistive port coupling the front cavity to space outside the headphone in parallel to the front reactive port, the front resistive port having a characteristic acoustic impedance of at least 2.0×10^7 kg/m^4 at 3 kHz.

25. A headphone comprising:

an ear tip configured to seal the headphone to an ear canal of a user to form an enclosed volume including the ear canal and a front cavity of the headphone,

a housing comprising an extended tab for retaining the ear tip, and

a front reactive port and a front resistive port coupling the otherwise-sealed front cavity to space outside the headphone in parallel, to provide a consistent response across the audible spectrum, wherein

the extended tab and ear tip cooperate to form a channel that surrounds the front reactive port, the channel protecting the front reactive port from blockage when the headphone is worn in the user's ear.

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